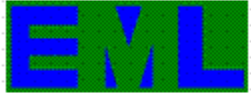


# Report on the 12<sup>th</sup> International Intercomparison of Environmental Dosimeters



## Organizers

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- US DOE - Environmental Measurements Laboratory
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- Rodolfo Cruz Suarez
- United Nations – International Atomic Energy Agency

Since 1974 (nearly 30 years), EML has co-organized the International Intercomparison of Environmental Dosimeters (IIED). This slide show reports on the results of the latest, 12th, IIED. This intercomparison was organized with assistance of the individuals in the institutions listed above. The intercomparisons provide information on the performance of the state of the art techniques in environmental dosimetry utilizing passive dosimeters. Each intercomparison has also been designed to investigate special topics in environmental dosimetry. Participation in each intercomparison was voluntary and individual results were kept anonymous.

## Participation



This intercomparison included 131 participants from 42 different countries. The participants were from the countries with red borders in the above map. In addition the flag of each of the countries is displayed in this image. In all, 173 sets of dosimeters were sent to EML to be included in the IIED. Note that several participants submitted more than one set of dosimeters to be included in the intercomparison. Results for 169 sets of dosimeters were submitted for analysis at the completion of the intercomparison.

## Testing Protocol

### Testing Protocol for 12<sup>th</sup> International Intercomparison

- **12 Dosimeters from Each Participant**
- **6 Treatment Groups (2 Dosimeters per Group)**

Treatment	Field Exposure <sup>a</sup> Dates	Laboratory Exposure <sup>b</sup> Dates
Control	None	None
Laboratory	None	August 3 & 4, 2000
Field	June 26 - September 27, 2000	None
Field-Beginning	June 26 - September 27, 2000	June 27 & 28, 2000
Field-Middle	June 26 - September 27, 2000	August 10 & 11, 2000
Field-End	June 26 - September 27, 2000	September 26 & 27, 2000

<sup>a</sup>BNL background location (approximately 72 nGy/h)

<sup>b</sup><sup>137</sup>Cs irradiation at BNL (78.3 uGy/min on 6/27/00)

- **Dosimeters returned to Participants**
- **Routine Analysis performed (blind) by Participants**
- **Gross Results reported to EML**
- **Interpretation and Reporting of Individual and Group Results**
- **Participant Anonymity is Maintained**

This image shows the protocol for this IIED. Each set consisted of 12 dosimeters, and each set was divided into 6 treatment groups: Control (no field or laboratory exposure), Laboratory (a laboratory exposure in the middle of the field period but not place in the field), Field (a three month field exposure but no laboratory exposure), Field-Beginning (a three month field exposure and a laboratory exposure at the beginning of the field period), Field-Middle (a three month field exposure and a laboratory exposure in the middle of the field period), and Field-End (a three month field exposure and a laboratory exposure at the end of the field period). The laboratory exposure was performed using a <sup>137</sup>Cs irradiator at BNL with 78.3uGy/min. The field exposure was provided at a background location at BNL with approximately 72nGy/h. This experimental design was adapted from the environmental category testing in Draft ANSI Standard N13.29 Environmental Dosimetry Performance Criteria for Testing. It investigates the performance of dosimeters relative to the time of irradiation during a field period. Once the field portion of the IIED was completed the dosimeters were returned to the participants. The participants were not informed of the treatment group for any of the dosimeters. They were asked to perform a routine analysis and report the results to EML. Results were then assimilated for interpretation and reports such as this prepared. Through the entire process participant anonymity is maintained.

## Types of Dosimeters

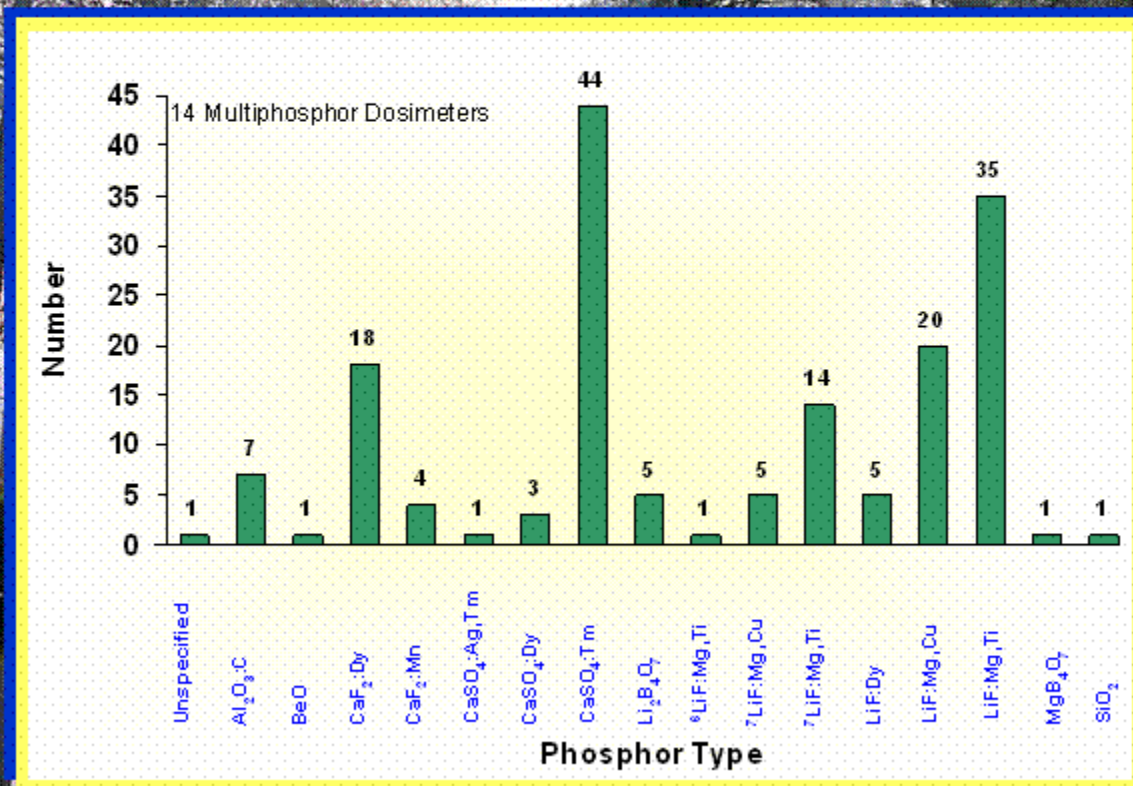
### Dosimeters Included in the 12<sup>th</sup> International Intercomparison

Dosimeter Type	Number
TLD	152
Electret	5
RPL Glass	3
GM Tube	2
OSL	2
Direct Ion Storage	1
Film	1
Optical Fiber	1
Silicon Diode	1
Unspecified	1

This table identifies the types of dosimeters submitted for this IIED. By far, the majority of dosimeters were TLDs. Dosimeter packages varied widely in appearance. Several dosimeter types are pictured in this image.

## Types of Phosphors

### TLD Phosphors in the 12<sup>th</sup> International Intercomparison



The TLD group is further broken down in this image by the phosphor type. There were 26 different phosphor compositions among the TLDs submitted. The most common phosphors were CaSO<sub>4</sub>:Tm, LiF:Mg,Ti, LiF:Mg,Cu, CaF<sub>2</sub>:Mn, and <sup>7</sup>LiF:Mg,Ti as identified in this image. There were 14 sets of dosimeters that utilized multiple phosphor elements.

## Preparation



On arrival at EML the shipping packages and individual dosimeters were scanned to ensure a lack of any residual contamination prior to storage. The packages were stored in EML's shielded room during periods of non-exposure. Dosimeters were assigned a unique alpha-numeric code. This was accomplished with barcode label that was attached to each dosimeter. A barcode reader and spreadsheet program was used to track the dosimeter during the testing phase. Field dosimeters were attached to deployment racks before being moved to the BNL field site.

## Calculating Results

### Determination of Net Results and Reference Values

Test Conditions	Barcode Designations	Determination of Net Dose: Calculations	Reference Value (uGy)
Control	B,D	$=(B+D)/2$	(none)
Laboratory	G,H	$=(G+H)/2-(B+D)/2$	391 +/- 11
Field	C,I	$=(C+I)/2-(B+D)/2 + \text{Storage Dose}^*$	160 +/- 10
Field Beginning	F,K	$=(F+K)/2-(C+I)/2$	548 +/- 16
Field Middle	E,L	$=(E+L)/2-(C+I)/2$	391 +/- 11
Field End	A,J	$=(A+J)/2-(C+I)/2$	623 +/- 18
		*Storage Dose =	32 +/- 1

### Basis for Reference Values

Laboratory	5 min $^{137}\text{Cs}$ irradiation	(78.1 uGy/min)
Field	Pressurized Ionization Chamber Monitoring Data	
Field Beginning	7 min $^{137}\text{Cs}$ irradiation	(78.3 uGy/min)
Field Middle	5 min $^{137}\text{Cs}$ irradiation	(78.1 uGy/min)
Field End	8 min $^{137}\text{Cs}$ irradiation	(77.9 uGy/min)
Storage Dose	Pressurized Ionization Chamber Monitoring Data	

At the completion of the exposure period the dosimeters were sent back to the participants who then were requested to perform the analysis and report the gross result for each dosimeter back to EML. Participants were asked to provide results as Air Kerma in units of uGy or Ambient Dose Equivalent in units of mSv. Data in International Commission on Radiation Units and Measurements Report 47 "Measurement of Dose Equivalents from External Photon and Electron Radiations" along with information about the exposure energies were used to make conversions between the two measurements. Specifically, the conversion factors used were 1.2, 1.2 and 1.1 Sv Gy<sup>-1</sup> were used for the laboratory, field and storage exposure respectively. Net results were calculated by the organizers based on the top table shown above. The reference values in uGy are also identified in this table. The reference values were determined using the techniques shown in the lower table.

## Storage Facility



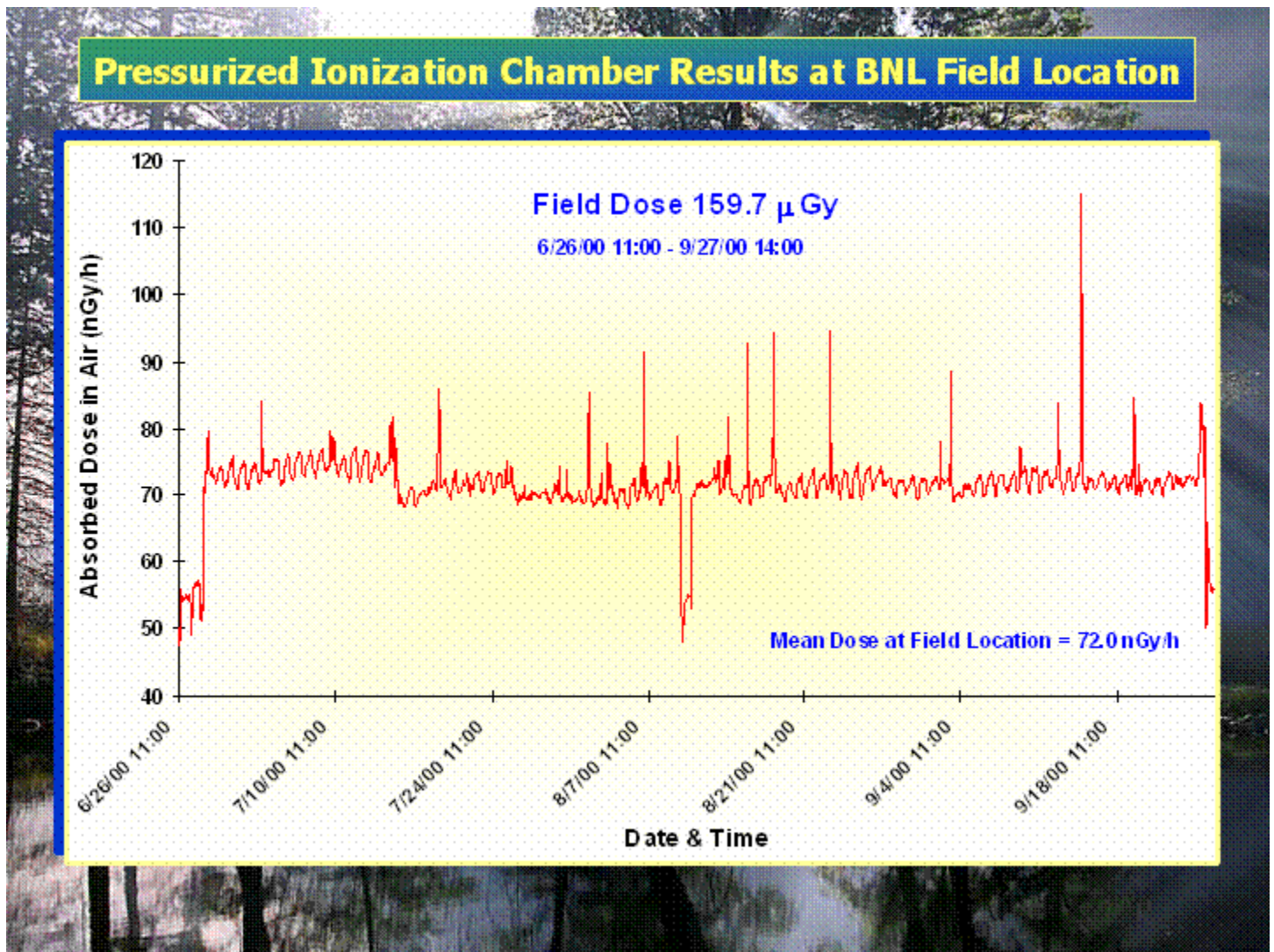
This photograph shows the shielded room used for storage of the dosimeters at EML. This facility was used to minimize exposure to control dosimeters and other dosimeters during periods of no testing exposure. The photo was taken prior to the beginning of the field period when dosimeters were being accepted for the intercomparison. The pressurized ionization chamber (PIC) is shown in the lower left-hand corner of the photo. The mean exposure rate in the storage area measured by the PIC is shown (14.4 nGy hr<sup>-1</sup>).

## Field Location



The photograph above shows the dosimeters hung from racks 1m above the ground in the field location at Brookhaven National Laboratory. Eight racks of dosimeters were deployed for this intercomparison. A PIC was maintained at the field site and measured exposure for the field period. The mean exposure rate for the field period is reported above, 72.1 nGy hr<sup>-1</sup>. All the racks and PIC were moved together when <sup>137</sup>Cs irradiations of various field groups were conducted.

## PIC Data



PIC data for the field period is shown in the figure above. The data shows typical diurnal fluctuations in dose rate related to atmospheric mixing and sporadic spikes related to rainout during precipitation. The data also shows three periods with lowered exposure rates corresponding to the movement and storage of the PIC and field dosimeters during the field-beginning, field-middle and field-end irradiations. This data was integrated to provide the Field Treatment Group reference value of 159.7  $\mu$ Gy.

## Irradiation Facility



The photographs above show the facility used to perform  $^{137}\text{Cs}$  irradiations. An arced rack was placed 1 m from the point source. The source was controlled using a pneumatic device and would appear on the stand shown in the bottom left of the larger photo. The controls for the irradiator are located outside the caged area and shown in the smaller photograph. The source resulted in an exposure rate of  $78.3 \text{ uGy min}^{-1}$  at the beginning of the intercomparison field period. Irradiations of all the dosimeters for each group took from 9 to 11 shots to complete. A minimum of 3 quality control TLDs were placed on the rack during each shot to verify uniformity of irradiations.

## QC Results

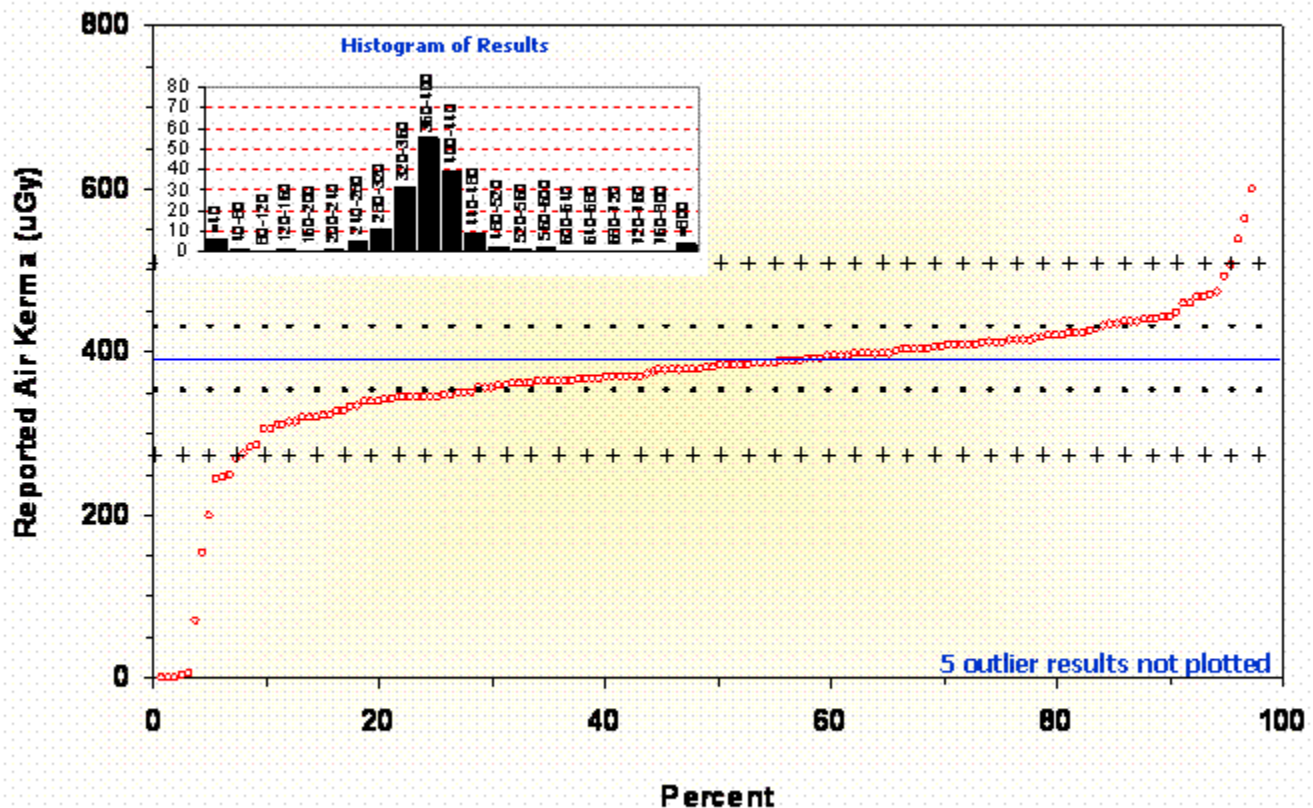
### Summary of Quality Control Results

Exposure Group	Number of Dosimeters	Measured Air Kerma (mean) $\mu\text{Gy}$	Uncertainty $\mu\text{Gy}$	Expected Air Kerma $\mu\text{Gy}$	Uncertainty $\mu\text{Gy}$	Overall Bias
Field	16	146	5	160	10	-8.8%
Field (Beginning)	22	566	21	548	16	3.2%
Field (Middle)	27	392	10	391	11	0.5%
Field (End)	32	608	12	623	18	-2.5%
Laboratory	30	388	12	391	11	-0.6%

The table above summarizes the results of quality control (QC) TLDs used in this intercomparison. The sixteen field QC TLDs were deployed during the field period and two were hung from each rack. These dosimeters showed a negative bias of 8.8% relative to the PIC-derived reference value. The remainder of the QC dosimeters were placed on the rack during  $^{137}\text{Cs}$  irradiations. These showed a lower bias relative to the reference value for all four irradiation groups. Prior to use as QC in this intercomparison, these TLDs were evaluated by NIST and successfully passed a proficiency test with an overall bias of  $-0.00\%$  and a standard deviation of  $0.04\%$ .

## Laboratory Treatment Results

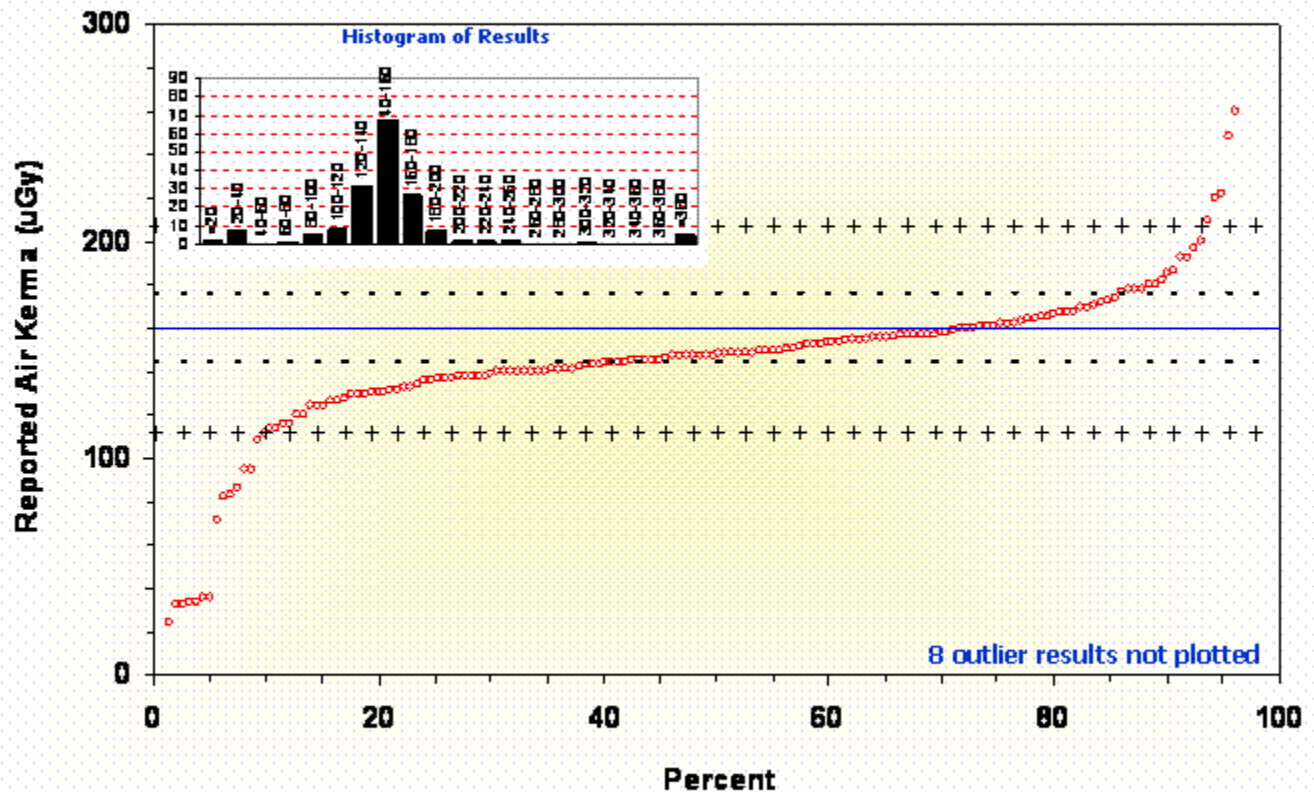
### Quantile Plot of Laboratory Treatment Results



The larger figure above shows a Quantile Plot of the results from the laboratory-irradiated treatment group. In this plot, horizontal slopes show results with little variation and increasing vertical slopes indicate large variations. Five data points which are less than 0 or greater than 800 uGy are not plotted on this scale. The solid blue line equals the reference value. The dashed lines are  $\pm 10\%$  and the + formed lines are  $\pm 30\%$  of the reference value. The plot displays clustering of data around the reference value. Variability of the data increases at the low and high extremes of the data set. The median is lower than the reference value; 57% of the results are lower than the reference value. A histogram of the data is plotted as an inset in this figure. It is another representation of the total data set that reinforces the above interpretation. The plot is a normal distribution with the highest frequency near the reference value. There is a relatively high incidence of extreme values ( $< 40$  and  $> 600$  uGy). This suggests that several of the reported results were grossly incorrect. No explanation is readily available for these extreme values.

## Field Treatment Results

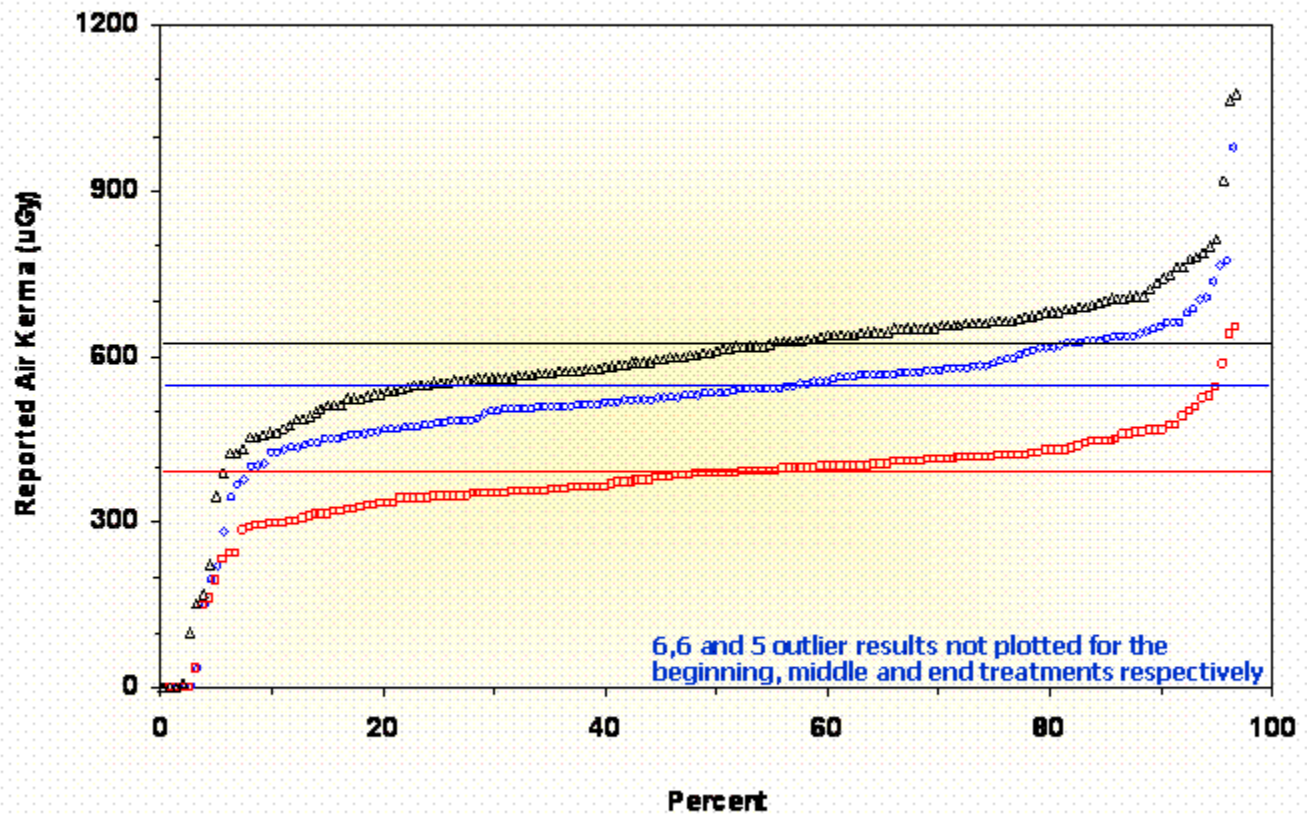
### Quantile Plot of Field Treatment Results



The larger figure shows a Quantile Plot of the results from the field treatment group results. Like the previous graphic the plot shows a fairly smooth curve with one plateau. In this case again, the median (50%) is less than the reference value. A much higher percentage of the data (73%) is below the reference value as compared to 57% for the laboratory-irradiated treatment group. This indicates an under response of the most of the dosimeters in this test relative to the PIC that was used to determine the reference value. An under response in the field test has been observed during previous intercomparisons and was specifically investigated in the 8th International Intercomparison of Environmental Dosimeters (IIED). The 8th IIED identified that there was as much as a 15% under response to cosmic radiation in many TLDs. The field treatment results of the 12th IIED were similar to the field treatment results of the 11th IIED that was conducted at the same location. There is a histogram plot as an inset to this figure that reveals the nearly normal distribution of the data. Once again, there are several extreme data (<40 or >380 uGy) that are unexplained.

## Laboratory and Field Treatment Results

### Quantile Plot of Field Beginning, Middle and End Treatment Results



This Figure shows a Quantile Plot for the field-beginning, field-middle and field-end treatment groups colored coded in blue, red and black respectively. The curves for each of these plots are similar and indicate clustering of the data around the reference values (solid lines of same color). In each case the medians are slightly below the reference values; 58, 53 and 55% of the data are below the reference value for the field-beginning, field-middle and field-end treatment groups respectively.

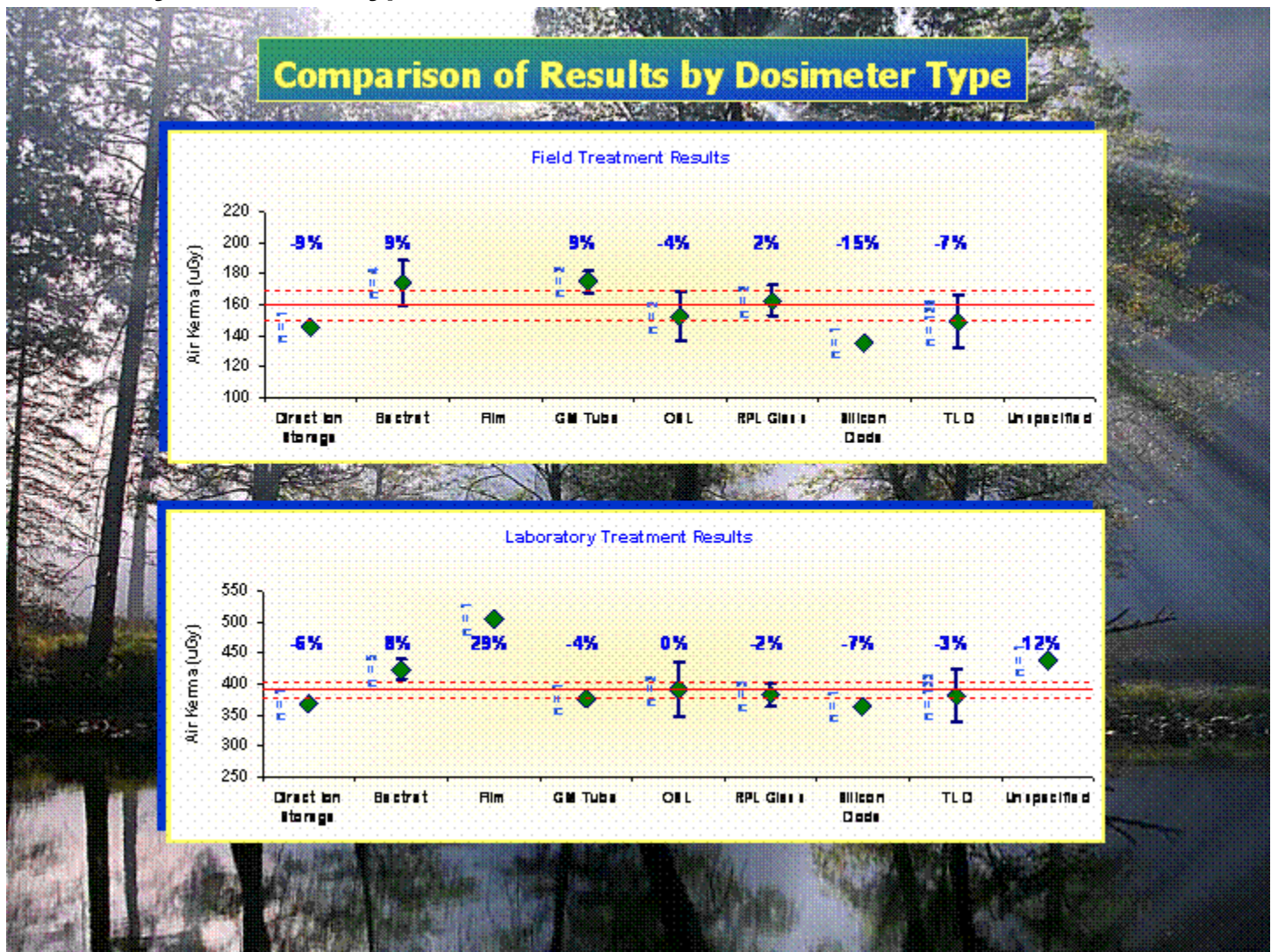
## Performance Results

### Summary of Performance compared to Reference Values and ANSI-N545

Treatment Group	Percentage of Dosimeters	
	Within 10% of Reference Values (Lab performance criteria)	Within 30% of Reference Values (Field performance criteria)
Laboratory	55%	88%
Field	46%	83%
Field Beginning	48%	87%
Field Middle	49%	86%
Field End	52%	87%

The table above shows the percent of results within 10% and 30% of the reference values for each of the treatment categories. The best performance was for the laboratory treatment group and the worst was the field treatment group. The American National Standard Institute document ANSI-N545 cites 10% and 30% as criteria for laboratory and field exposures respectively. 55% of the laboratory treatment results and 79% of the field treatment results met these criteria. The remaining treatment groups included both a laboratory and a field exposure so these criteria do not strictly apply to this standard, but the reference value is based on the laboratory exposure only. For these three categories, the performance seems to increase slightly as the laboratory exposure occurs later in the field period as indicated by percent of results within 10% of the reference value.

## Results by Dosimeter Type



The two plots above show the results of the field and laboratory treatment groups as a function of dosimeter type. The mean  $\pm 1$  standard deviation for each dosimeter type is plotted. Outliers (greater than 30% of the reference value) were removed for this analysis. The number of results reported for each dosimeter type is indicated next to the plotted symbol. The bias relative to the reference value is written above the symbol. The solid line indicates the reference value in each plot. The dashed lines represent  $\pm 6$  and  $3\%$  of the reference value in the field treatment and laboratory treatment plots respectively. Only TLD and electrets have enough reported measurements to make reasonable inferences with statistical power. The other types of dosimeters are plotted for general comparison. In both plots the mean TLD result was lower than the reference value ( $7\%$  for the field treatment and  $3\%$  for the laboratory treatment) and the mean electret result was higher than the reference value ( $9\%$  for the field treatment and  $8\%$  for the laboratory treatment).

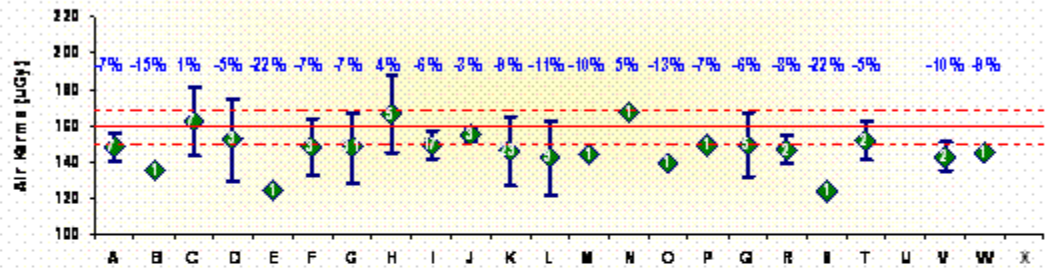
## Results by Phosphor Type

### Comparison of Results by Phosphor Type

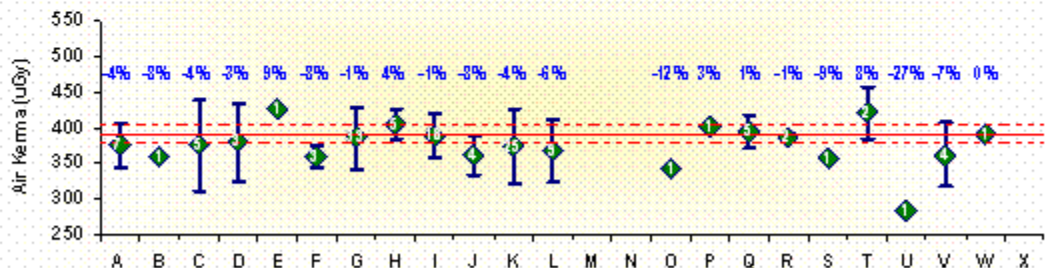
#### Code Phosphor

A	...	Al <sub>2</sub> O <sub>3</sub> :C
B	...	CaF <sub>2</sub>
C	...	CaF <sub>2</sub> :Dy
D	...	CaF <sub>2</sub> :Mn
E	...	CaSO <sub>4</sub> :Ag,Tm
F	...	CaSO <sub>4</sub> :Dy
G	...	CaSO <sub>4</sub> :Tm
H	...	LiF:Dy
I	...	LiF:Mg,Cu,P
J	...	<sup>7</sup> LiF:Mg,Cu,P
K	...	LiF:Mg,Ti
L	...	<sup>7</sup> LiF:Mg,Ti
M	...	MgB <sub>4</sub> O <sub>7</sub>
N	...	SiO <sub>2</sub>
O	...	<sup>7</sup> LiF:Mg,Cu,P/LiF:Mg,Ti
P	...	<sup>7</sup> LiF:Mg,Ti/ <sup>6</sup> LiF:Mg,Ti
Q	...	CaF <sub>2</sub> :Dy/LiF:Mg,Ti
R	...	CaF <sub>2</sub> :Dy/ <sup>7</sup> LiF:Mg,Ti
S	...	CaF <sub>2</sub> :Dy/CaSO <sub>4</sub> :Dy
T	...	CaSO <sub>4</sub> :Tm/CaSO <sub>4</sub> :Dy
U	...	Li <sub>2</sub> B <sub>4</sub> O <sub>7</sub> /CaSO <sub>4</sub> :Dy
V	...	Li <sub>2</sub> B <sub>4</sub> O <sub>7</sub> /CaSO <sub>4</sub> :Tm
W	...	LiF:Mg,Ti/ <sup>7</sup> LiF:Mg,Ti
X	...	BeO

#### Field Treatment Results

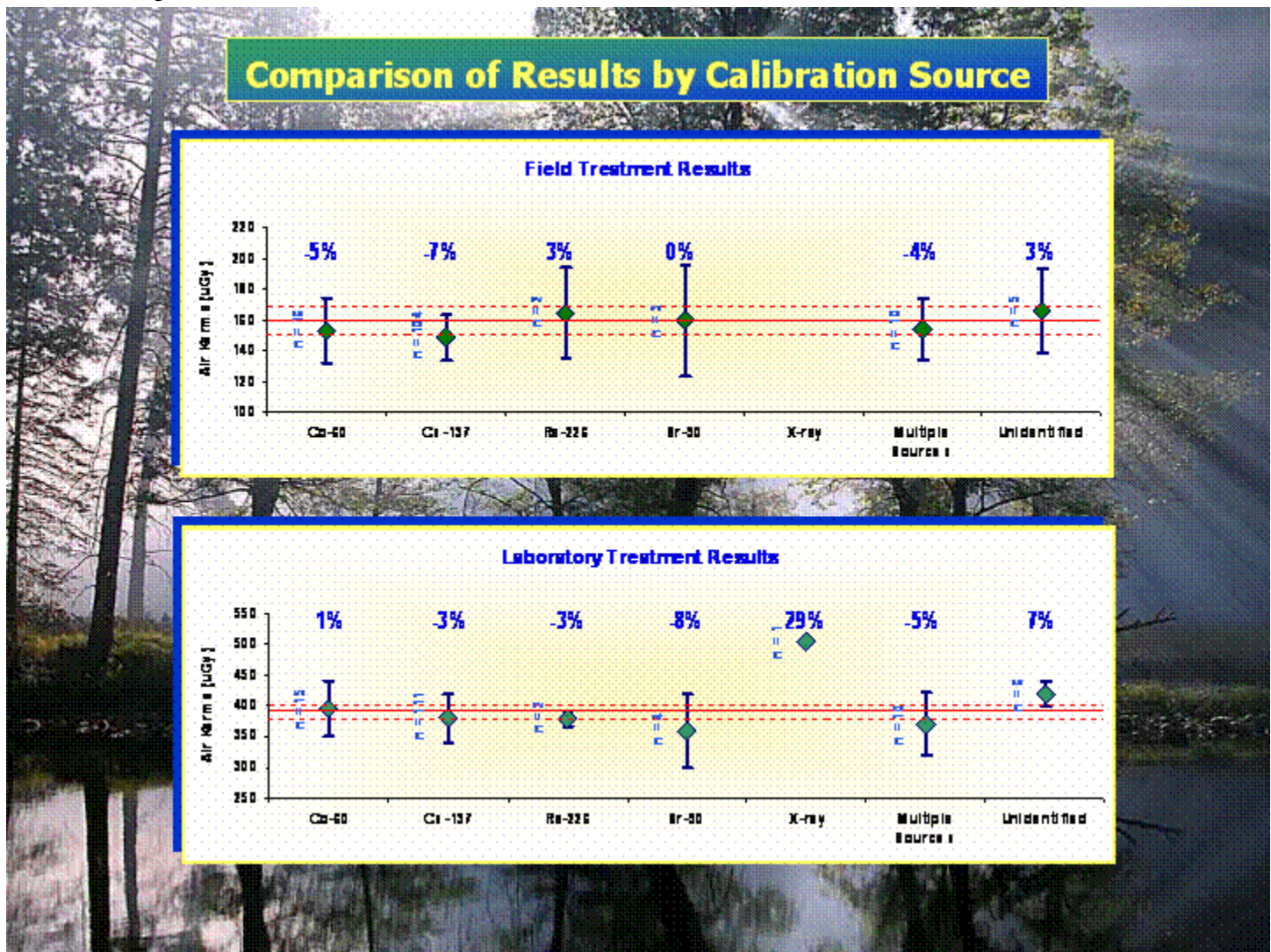


#### Laboratory Treatment Results



Since the vast majority of dosimeter results in this intercomparison were from TLDs this group was looked at in more detail. The two plots above show the results of the field and laboratory treatment groups as a function of the TLD phosphor. The mean  $\pm 1$  standard deviation for each phosphor is plotted. Outliers (greater than 30% of the reference value) were removed for this analysis. A key is provided to indicate each of the 24 phosphor combinations that are plotted. The number of results reported for each phosphor is indicated in the plotted symbol. The bias relative to the reference value is written above the symbol. The solid line indicates the reference value in each plot. The dashed lines represent  $\pm 6$  and  $3\%$  of the reference value in the field treatment and laboratory treatment plots respectively. The most common TLD phosphors were CaSO<sub>4</sub>:Tm, LiF:Mg,Ti, LiF:Mg,Cu,P, CaF<sub>2</sub>:Dy and <sup>7</sup>LiF:Mg,Ti and the mean result of each of these phosphors was  $-7$ ,  $-9$ ,  $-6$ ,  $+1$  and  $-11$  percent of the reference value in the field treatment group respectively and  $-1$ ,  $-4$ ,  $-1$ ,  $-4$  and  $-6$  percent of the reference value in the laboratory treatment group respectively.

## Results by Calibration Source



The two plots above show the results of the field and laboratory treatment groups as a function of the dosimeter calibration source. The mean  $\pm 1$  standard deviation for each type of calibration source is plotted. Outliers (greater than 30% of the reference value) were removed for this analysis. The number of results reported for each source is indicated next to the plotted symbol. The solid line indicates the reference value in each plot. The dashed lines represent  $\pm 6$  and  $\pm 3\%$  of the reference value in the field treatment and laboratory treatment plots respectively. Most of the dosimeter results reported were calibrated using  $^{137}\text{Cs}$ , and several were calibrated using  $^{60}\text{Co}$ . There were too few of the reported results that used other calibration sources to make statistically significant comparisons. These results are plotted for general comparison. The results of this intercomparison agree with the 9th International Intercomparison of Environmental Dosimeters that investigated the effect of calibration source in more detail. Results of dosimeters calibrated with  $^{137}\text{Cs}$  are up to consistently a few percent lower than the results with  $^{60}\text{Co}$  as a calibration source. The  $^{137}\text{Cs}$  calibrated dosimeters reported results that were 2% lower than the  $^{60}\text{Co}$  calibrated dosimeters in the field treatment group and 4% lower in the laboratory treatment group. The results of dosimeters calibrated with either source are within  $\pm 10\%$  of the reference value for both treatments.

# Conclusions

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- The majority of the dosimeters included in the 12<sup>th</sup> International Intercomparison of Environmental Dosimeters were TLDs (152 out of 169 sets reporting results) but there were 24 phosphor combinations used among these TLDs.
- $\text{CaSO}_4:\text{Tm}$ ,  $\text{LiF:Mg,Ti}$ ,  $\text{LiF:Mg,Cu,P}$ ,  $\text{CaF}_2:\text{Dy}$  and  $^7\text{LiF:Mg,Ti}$  were the most common phosphors used (ordered by decreasing presence)
- QC results using TLD-700 indicated a negative bias (-8.8%) relative to the PIC used as a reference measurement for the field exposure.
- QC results for the  $^{137}\text{Cs}$  irradiations were within  $\pm 5\%$  of the reference values.

# Conclusions

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- Results for all five treatment groups approximate a smooth normal distribution with tight clustering around the reference values.
- The median for all five treatment groups was below the reference value (About 57, 73, 58, 53, and 55% of the results were below the Laboratory, Field, Field-Beginning, Field-Middle and Field-End reference values respectively).
- The apparent negative bias of field exposed dosimeters has been observed in past intercomparisons and is potentially due in part to an under response of some dosimeters to cosmic radiation.
- The overall performance was similar to previous intercomparisons (55% of the Laboratory treatment group and 83% of the Field treatment met the ANSI N545 criteria).
- The performance of the treatment groups with both a laboratory and a field exposure, as suggested in Draft ANSI Standard N13.29, were between those of the laboratory and field only treatment groups.
- There was slight improvement in performance when the laboratory exposure occurred nearer the end of the field period among the combined Field and Laboratory irradiated treatments.

# Conclusions

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- The mean TLD result was 7 and 3% lower than the reference values for the Field and Laboratory treatment groups respectively. The Electret result was 9 and 8% higher than the reference values. There was an insufficient sample size to provide reliable statistics on the performances of other dosimeter types.
- Mean Results in the Field Treatment group for the most common TLD phosphors showed deviations of -7, -9, -6, +1, and -11% from the reference value for  $\text{CaSO}_4:\text{Tm}$ ,  $\text{LiF:Mg,Ti}$ ,  $\text{LiF:Mg,Cu,P}$ ,  $\text{CaF}_2:\text{Dy}$  and  $^7\text{LiF:Mg,Ti}$  respectively.
- Mean Results in the Laboratory Treatment group for the most common TLD phosphors showed the deviations of -1, -4, -1, -4, and -6% from the reference value for  $\text{CaSO}_4:\text{Tm}$ ,  $\text{LiF:Mg,Ti}$ ,  $\text{LiF:Mg,Cu,P}$ ,  $\text{CaF}_2:\text{Dy}$  and  $^7\text{LiF:Mg,Ti}$  respectively.
- As identified in previous intercomparisons the dosimeters calibrated with  $^{137}\text{Cs}$  reported slightly lower results (<5%) than those calibrated with  $^{60}\text{Co}$ . There was an insufficient sample size to provide reliable statistics on the performances of dosimeters calibrated by other methods.